Final Project

PUBH 8878, Statistical Genetics

Purpose

- Analyze real genetic data using methods from the course. Choose one of the tracks below (or propose your own) and produce a succinct, reproducible analysis using a public dataset.
- This project emphasizes scientific reasoning, correct statistical practice, clear communication, and reproducible code. It is intentionally open-ended: depth > breadth.

Deliverables

- Project proposal (approx. 1 page): question(s), dataset(s), methods, risks/mitigations, expected outputs. **Due: Wednesday, October 15th by 11:59pm.**
  - Ensure that you are able to access/download your proposed dataset(s)
- Final report (8–12 pages, PDF only): format details below. **Due: Wednesday, November 12th by 11:59pm.**
  - Reproducible materials: a self-contained folder or repo with your `.qmd`/R scripts, environment notes, and seeds. Include a `README` with run instructions.
- 8–10 minute in-class presentation of key results on **Wednesday, November 12th**

Format

We will follow the format of the journal Genetics. An Overleaf template can be found here. The paper should adhere to the following:

- Begin the paper with an original title, followed by your name, the course, and the date
- The paper should have the following sections:
  - Introduction: state the general problem or issue you are addressing.

  - Materials and Methods: describe the methods used to obtain data, analyze data, and to test hypotheses associated with the data.
  - Results: describe the results of the data analysis and hypothesis testing.
  - Discussion: here you draw conclusions about the problem you studied; this section should include a synthesis of ideas.
  - References: List the relevant literature you have read and used to support your arguments/analyze your data. The literature cited should be in the format of the journal Genetics.

Evaluation (20% of course grade)

- Clarity and scope (20%): well-posed question, appropriate scope for time/resources.
- Methods and correctness (35%): sound statistical modeling, assumptions stated, correct inference, sensible QC.
- Interpretation and communication (25%): figures/tables support claims, limitations, ethical awareness.
- Reproducibility (20%): organized code, seeds, instructions, figures regenerate.

Example Topics

- Primary GWAS analysis (individual-level data): perform QC, PCA, GWAS, and post-GWAS analyses. Data is typically available for non-human model organisms.
- Secondary GWAS analysis (summary statistics): pick one trait and perform quality checks, Manhattan plot, locus zoom(s), gene/annotation enrichment, and short literature triangulation, SNP-heritability via LD Score Regression, cross-trait genetic correlation.
- Population structure and diversity: PCA/UMAP on a reference genotype panel, compute F_{ST} between populations, visualize allele frequency spectra, explore LD decay, ADMIXTURE/LEA ancestry components.
- Causal inference with two-sample Mendelian randomization: select a well-powered exposure/outcome with strong instruments, run multiple MR estimators, perform sensitivity and heterogeneity checks, discuss assumptions and violations.
- Fine-mapping or colocalization: focus on 1–2 loci, use LD from a reference panel, apply SuSiE/FINEMAP, test GWAS–eQTL colocalization for a tissue of interest.
- Simulation with real LD: simulate phenotypes on a real genotype panel (e.g., chromosome 22) to study power, inflation, or PRS performance under different architectures.

Ethics & Responsible Use

- Use population labels with care
- Avoid essentialist interpretations

- Discuss portability and fairness when comparing groups
- Do not attempt re-identification
- Respect each dataset's license/terms.

Data Sources (curated)

- GWAS Catalog (NHGRI–EBI): comprehensive registry of GWAS with summary statistics where available; good for trait curation and downloading per-study results.
- OpenGWAS (MRC IEU): programmatic access to >40k GWAS summary-stat datasets; integrates well with R packages `ieugwasr` and `TwoSampleMR`.
- Pan-UK Biobank (Broad): pan-ancestry GWAS results across thousands of phenotypes with interactive PheWeb and bulk download.
- FinnGen: large disease-focused GWAS summary stats and phenotype documentation.
- Biobank Japan: GWAS results across many traits; multi-ancestry comparison opportunities.
- GIANT Consortium: anthropometric trait GWAS (e.g., height, BMI) — classic, clean testbeds.
- Psychiatric Genomics Consortium (PGC): summary stats for psychiatric disorders; read and follow data use terms.
- 1000 Genomes Project (IGSR): open, phased whole-genome reference panel with population labels; ideal for PCA, F_ST, LD, and as an LD reference.
- HGDP + 1000G combined callset (gnomAD): harmonized WGS panel for global structure analyses (VCF/PLINK).
- gnomAD v4: aggregated exome/genome allele frequencies; excellent for frequency-based analyses and QC (not individual-level genotypes).
- GTEx/eQTL resources and GTEx v8 summary statistics for colocalization.
- LD reference (for LDSC/fine-mapping) and baseline annotations: precomputed 1000G LD scores.

Model-organism data sources (genotypes + phenotypes where noted)

- (Mouse) Mouse Phenome Database (MPD): strain, Collaborative Cross (CC), and Diversity Outbred (DO) resources with extensive phenotypes. Måany datasets include genotypes or QTL-ready files. Good for GWAS/QTL and replication.
- (Mouse) International Mouse Phenotyping Consortium (IMPC): high-throughput knockout phenotypes with rich metadata. Best for functional interpretation.
- (Mouse) MGI (Mouse Genome Informatics): curated QTL/phenotype annotations and cross references.
- (Mouse/Rat) GeneNetwork: genotypes and thousands of phenotypes for reference panels (e.g., BXD, LXS, HXB/BXH). Interactive QTL mapping and downloads.

- (Rat) Rat Genome Database (RGD) and PhenoMiner: strain genotypes/variants with curated phenotypes, supports QTL/GWAS in rat panels.
- (Drosophila) Drosophila Genetic Reference Panel (DGRP): fully inbred lines with whole-genome genotypes and many published phenotypes, designed for GWAS across lines.
- (Drosophila) FlyBase: genome and phenotype annotations, links to population panels and datasets.
- (C. elegans) CeNDR: natural isolates with genotypes and trait data, built-in GWAS and download portal.
- (C. elegans) WormBase: phenotype and functional annotations, pairs well with CeNDR for interpretation.
- (Arabidopsis) AraGWAS Catalog and AraPheno: GWAS results, phenotypes, and links to 1001 Genomes genotypes, GWAS-ready.

Helpful Resources by Topic

Here are some resources for topics that we will not cover in depth in this course, if you choose to explore them for this project.

Causal inference (Mendelian randomization)

- TwoSampleMR documentation and ieugwasr: end-to-end two-sample MR from OpenGWAS, with instrument selection, Steiger filtering, heterogeneity, and sensitivity analyses.
- MendelianRandomization (CRAN): MR-Egger, IVW, weighted median/mode, useful for triangulation.
- MR-PRESSO (CRAN): outlier detection/correction to assess horizontal pleiotropy.
- CAUSE: robust MR under correlated pleiotropy, helpful when standard assumptions are doubtful.

Fine-mapping and colocalization

- susieR: Bayesian variable selection and credible sets for fine-mapping; works with in-sample or reference LD.
- FINEMAP: summary-stat fine-mapping with shotgun stochastic search, supports multiple causal variants per locus.
- coloc: Bayesian colocalization testing for two traits (e.g., GWAS–eQTL), simple priors, clear summaries.
- eCAVIAR: probabilistic colocalization allowing multiple causal variants, requires LD and summary stats.

Simulation with real LD

- GCTA — simulate phenotypes: `--simu-qt`/`--simu-cc` generate traits on top of real genotype panels (e.g., chr22 PLINK files) using specified architectures.
- bigsnpr: R tooling for large genotype matrices. Simulate phenotypes with real LD and evaluate polygenic methods efficiently.
- HAPGEN2: simulate new genotypes from reference haplotypes (1000G/UKBB) to preserve realistic LD patterns.
- msprime/stdpopsim and stdpopsim: coalescent simulations with recombination and demographic models, combine with empirical LD panels for hybrid designs.